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## SUMMARY

Friction and wear studies were conducted to determine boundary-lubrication characteristics of four high-temperature liquid lubricants. The lubricants were a polyphenyl ether, a chlorinated methylphenyl silicone, a paraffinic resin, and a polypropylene. The fluids were examined at ambient temperatures to 1000° F. Measurements were made with the oil as received (containing the normal entrained gases), degassed, and degassed with 10 percent dibromotetrafluoroethane added as a flammability suppressor and an extreme-pressure agent.

The experiments were conducted with a 3/16-inch-radius rider sliding on a $2\frac{1}{2}$-inch-diameter disk specimen. The disk was rotated at surface sliding speeds to 8000 feet per minute. In all experiments the disk and the rider were of the same material, René 41. The lubricant was supplied to the specimen surface at the rate of 0. 55 cubic centimeter per minute in a nitrogen-gas stream.

Minimum friction and wear were obtained with the nondegassed chlorinated methylphenyl silicone. This fluid, however, produced the greatest amount of solid decomposition products on the specimen surface at 1000° F. Degassing of three of the oils had no conclusive effect on the friction and wear experiments obtained with the oils. The polyphenyl ether, however, appeared to be adversely affected by degassing.

Dibromotetrafluoroethane was effective in increasing the spontaneous-ignition temperature of all fluids examined except the polyphenyl ether. In aiding lubrication the dibromotetrafluoroethane additive was relatively ineffective with the polyphenyl ether and the polypropylene; however, it was beneficial in affording surface protection with the paraffinic resin and the silicone at 1000° F.

# INTRODUCTION

High operating temperatures of advanced aircraft and space-vehicle power systems require lubricating fluids with great thermal stabilities and high flammability temperatures. Diesters have been found suitable to bulk fluid temperatures of 350° F; with more advanced systems the triesters have been found suitable to 425° F (ref. 1), and current research has been seeking fluids that will operate at temperatures of 500° F (refs. 1 to 3). As fluids are being examined for use at these temperatures, consideration is being given advanced-aircraft flight speeds in the range Mach 3. 5 to 4. 0. Here bulk oil temperatures may reach 700° F (ref. 1). There is, however, a very limited number of fluids available at present that may be useful at such temperatures. Some of the fluids being examined for use at bulk temperatures of 500° F and above include the polyphenyl ethers, the superrefined mineral oils, heavy esters with suitable oxidation inhibitors, and silicones in oxygen-free environments (refs. 4 to 6).

As the operating temperatures of lubricating and hydraulic fluids increase, considerable concern is evident with regard to such properties as flashpoint, fire point, and spontaneous-ignition temperature. Since flammability can be a problem with lubricants and hydraulic fluids in or at relatively high temperatures, much research has been conducted through the years with oil additives designed to reduce flammability. One class of materials that has been examined as flame suppressants is the halogen-containing compounds. The bromine-containing compounds (e. g. , 1, 1, 2, 2, -tetrabromoethane, 1, 3-dibromopropane, and carbon tetrabromide) have been found to be among the better snuffer agents (ref. 7).

Another factor of some concern with high-temperature lubricating and hydraulic fluids is entrained gases. At high surface temperatures, the chemical reaction of oxygen and water present in the oil with metal surfaces may result in the formation of surface metallic oxides, which will prevent surface adhesion and welding. With advanced aircraft and space-vehicle systems, the high altitudes (low ambient pressures) and the high operating temperatures of the oil may result in degassing of the oil. This degassing process will result in the removal or loss of water, oxygen, nitrogen, etc. , from the oils.

The high operating temperatures in lubricated systems of advanced aircraft engines and the problem associated with the thermal stability of lubricants have resulted in consideration of a type of lubrication-system alternate to the conventional recirculating type. This system is termed the once-through or throw-away system. In such a system, the lubricant is supplied to the part to be lubricated in small quantities, is passed through the system, and is then vented. An inert gas can be used to blanket the lubricated component and thus reduce oxidation.

The objectives of this investigation were (1) to determine the lubricating character-

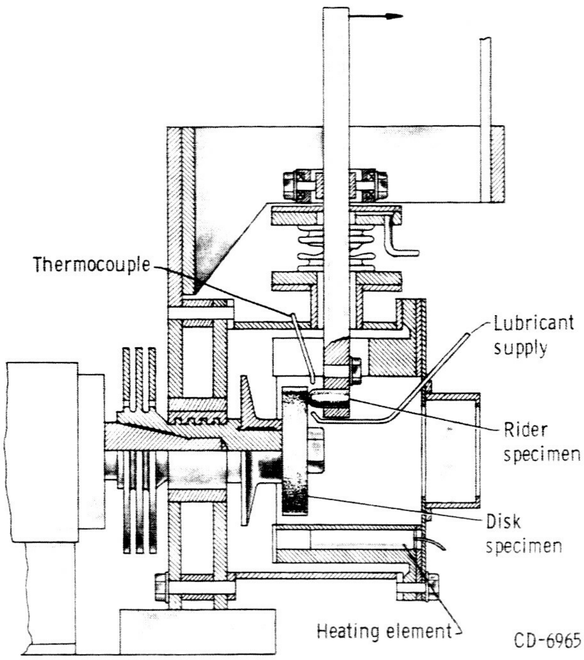


Figure 1. - High-temperature friction apparatus.

istics of four oils with a once-through lubrication system utilizing René 41 as the material to be lubricated, (2) to determine the influence of a halogen-containing gas, dibromotetrafluoroethane, on the lubricating characteristics of the oil, and (3) to determine the influence of entrained gases (oxygen, nitrogen, and water) on the lubricating characteristics of the four lubricants.

Friction and wear experiments were conducted in this investigation with a 3/16-inch-radius rider hemisphere sliding on a rotating $2\frac{1}{2}$-inch-diameter disk specimen at $75^{\circ}$, $500^{\circ}$, and $1000^{\circ}$ F. The oils studied were a polyphenyl ether, a chlorinated silicone, a paraffinic resin, and a polypropylene. The lubricant was supplied as a mist at 0.55 cubic centimeter per minute in a nitrogen atmosphere.

## APPARATUS AND PROCEDURE

The friction and wear apparatus used in this investigation is shown schematically in figure 1. The basic elements of the apparatus consist of a rotating disk specimen ($2\frac{1}{2}$-in.-diam. René 41) and a hemispherically tipped rider (3/16-in.-rad. René 41).

The rider specimen is stationary and in sliding contact with the rotating disk specimen. The disk specimen is rotated by means of a variable-drive unit through a gearbox and spindle assembly. Rotative speeds from 60 to 10 000 feet per minute can be obtained with the apparatus. The spindle assembly has a shaft extension fitted to it. The extension contains a series of fins with holes appropriately drilled to function as an air pump and to cool the drive shaft. The shaft enters the housing of the apparatus through an interlocking labyrinth seal. Attached to the drive shaft inside the apparatus is a heat shield and the disk specimen. A magnetic pickup is used to monitor rotative speeds.

The rider specimen is loaded against the disk surface by means of a retaining arm that is gimbal mounted to the apparatus and sealed with a flexible bellows. The load is applied to the arm by means of dead weights at a right angle to the loading. A linkage connects the arm with a strain-gage assembly for measuring frictional force.

The disk specimen is heated by means of an induction heater that fits around the

TABLE I. - PHYSICAL PROPERTIES OF LUBRICATING FLUIDS STUDIED

| Physical property | Lubricating fluid | | | |
|---|---|---|---|---|
| | Polyphenyl ether (five-ring isomeric) | Chlorinated methylphenyl silicone | Paraffinic resin | Polypropylene |
| Boiling point, $^{\circ}F$ | 982 | ---- | ---- | ----- |
| Pour point, $^{\circ}F$ | 40 | -100 | 20 | 20 |
| Viscosity, centistokes | | | | |
| at $100^{\circ}$ F | 366 | 52 | 4000 | 5400 |
| at $210^{\circ}$ F | 13.05 | 16 | 135.8 | 100 |
| Flashpoint, $^{\circ}F$ | 540 | 550 | 625 | 405 |
| Fire point, $^{\circ}F$ | 640 | --- | 730 | --- |
| Spontaneous-ignition temperature, $^{\circ}F$ | 1030 | 900 | --- | --- |
| Initial thermal-decomposition temperature, $^{\circ}F$ | 860 | 514 | --- | --- |
| Specific gravity | 1.20 at $68^{\circ}$ F | 1.05 at $77^{\circ}$ F | 0.9126 | 0.861 |
| Color | Colorless to pale yellow | Colorless to pale yellow | Brown | Colorless |
| Refractive index | ------------ | 1.4280 at $77^{\circ}$ F | ------ | 1.4750 |
| Carbon residue | ------------ | -------------- | [a]2.05 | ------ |

[a]Ramsbottom method.

TABLE II. - DISSOLVED OXYGEN AND NITROGEN IN AS-RECEIVED OILS AS DETERMINED BY GAS CHROMOTOGRAPHY

| Lubricating fluid | Gas volume in oil at standard temperature and pressure, cc/liter | Total oxygen and nitrogen in oil, mg/liter | Oxygen in oil, mg/liter | Nitrogen in oil, mg/liter | Ratio of nitrogen to oxygen |
|---|---|---|---|---|---|
| Polyphenyl ether (five-ring isomeric) | 45.9 | 47.25 | 15.95 | 31.30 | 1.96 |
| Paraffinic resin | 42.6 | 43.80 | 16.88 | 26.92 | 1.59 |
| Chlorinated methylphenyl silicone | 137.7 | 141.85 | 42.24 | 99.61 | 2.36 |
| Polypropylene | 88.3 | 90.80 | 19.80 | 71.00 | 3.59 |

circumferential surface of the disk. Temperature is measured with a thermocouple located adjacent to the disk. The apparatus was run at temperatures from $75^{\circ}$ to $1000^{\circ}$ F.

The experimental lubricants were introduced into the test chamber (0.7 liter capacity) by means of a stainless steel tube. An exhaust tube was used to remove effluent material. A face cover plate containing a quartz window for experimental observations was bolted to the outer apparatus housing.

All disk and rider specimens used in this investigation were finish ground to 4 to 8 microinches. Before each run the disk and rider specimens were given the same preparatory treatment. This treatment consisted of the following: (1) thorough rinsing with acetone to remove oil and grease from the surface, (2) polishing with moist levigated alumina and a soft polishing cloth, (3) thorough rinsing in tap water followed by rinsing in distilled water, and (4) final rinsing with ethyl alcohol.

The friction and wear experiments were conducted with a load of 1000 grams and a surface speed of 4600 feet per minute. The runs were of 1-hour duration. The oils were examined under three sets of conditions: (1) as received, (2) degassed, and (3) degassed with 10 percent by volume liquid dibromotetrafluoroethane added.

The lubricant was supplied by a mechanically driven glass syringe with a variable-speed coupling for the adjustment of flow rates. The lubricant was expelled from the syringe at a rate of 0.55 cubic centimeter per minute into a stream of liquid-nitrogen-dried nitrogen gas (moisture was removed with a liquid-nitrogen condenser) and carried to the disk-specimen surface. This was done outside the apparatus. The lubricants used in this investigation, with their physical properties, are described in table I.

## RESULTS AND DISCUSSION

In order to obtain quantitative measurements of the total amount of nitrogen and oxygen entrained in the oils, some gas-chromotography determinations were made with the four oils used in this investigation, and the results obtained are presented in table II. The gas-chromotography technique used is described in reference 8. The as-received oils examined were a polyphenyl ether (five-ring isomeric), a paraffinic resin, a chlorinated methylphenyl silicone, and a polypropylene. An examination of table II indicates that the silicone contained the largest quantity of entrained gas. The lubricant containing the least amount of entrained gas was the paraffinic resin. It is interesting to note here that the paraffinic resin had been degassed and purged with dry nitrogen by the supplier in processing the lubricant. The

TABLE III. - DISSOLVED WATER IN OILS AS DETERMINED BY KARL FISCHER METHOD

| Lubricating fluid | Water, ppm |
|---|---|
| Polyphenyl ether (five-ring isomeric) | 352 |
| Paraffinic resin | --- |
| Chlorinated methyl-phenyl silicone | 218 |
| Polypropylene | 101 |

two gases that were quantitatively measured were oxygen and nitrogen. The gases were not absorbed in the oil in the same ratio as would be encountered in air. In each case the quantity of oxygen entrained in the oil was greater than would be obtained from air (oxygen-nitrogen mixture).

The concentrations of water in the as-received oils used in this investigation were determined by the electrometric Karl Fischer method, and the results obtained are presented in table III. The largest concentration of water was found in the polyphenyl ether (352 ppm), while the least amount was obtained with the polypropylene (101 ppm).

Friction and wear experiments were conducted with René 41 sliding on René 41 at

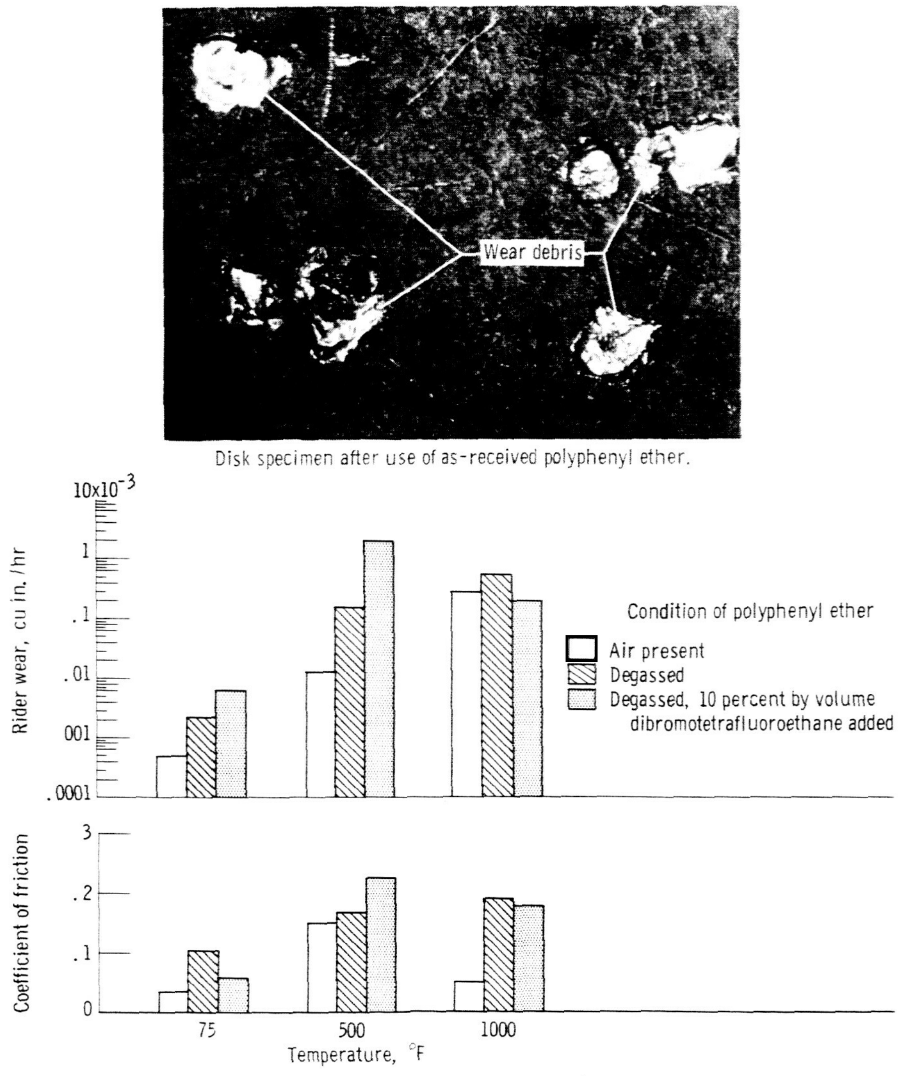
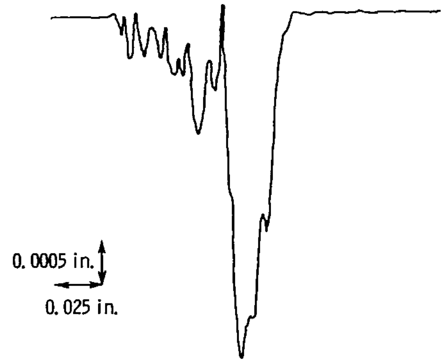



Figure 2. - Coefficient of friction and rider wear for René 41 sliding on René 41 at various ambient temperatures. Lubricant, polyphenyl ether; flow rate, 0.55 cubic centimeter per minute; atmosphere, nitrogen; sliding velocity, 4600 feet per minute; load, 1000 grams; run duration, 1 hour.




(a) Degassed polyphenyl ether.

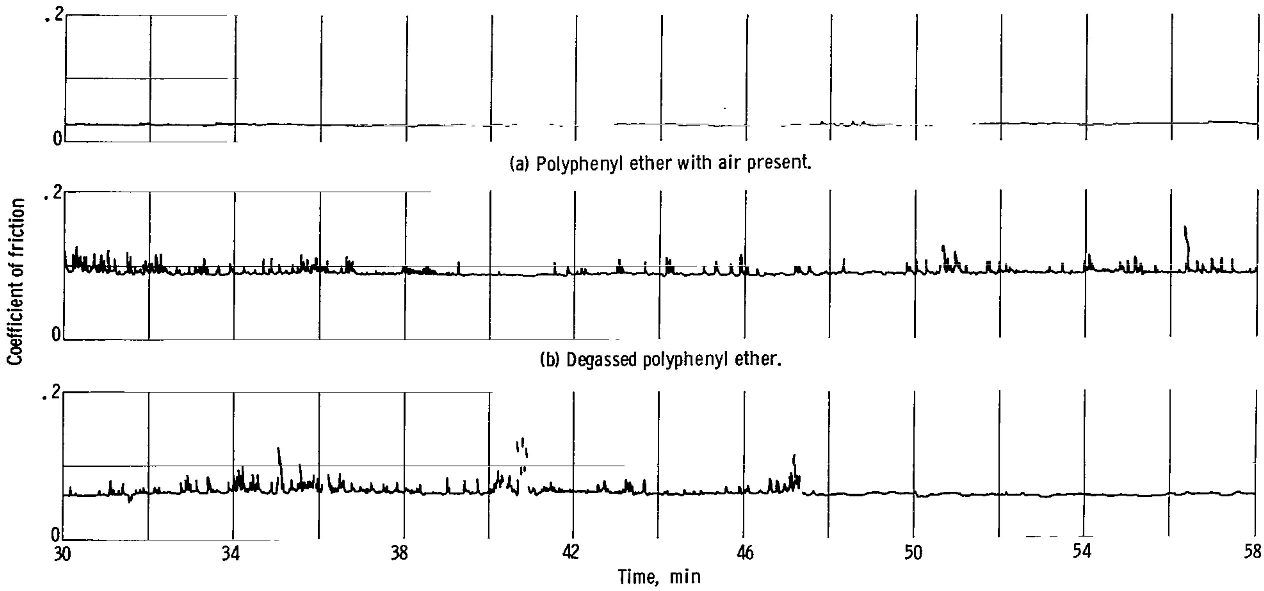
(b) Degassed polyphenyl ether with 10 percent by volume dibromotetrafluoroethane added.

Figure 3. - Surface profile traces of wear area of René 41 disks. Rider, René 41; flow rate, 0.55 cubic centimeter per minute; atmosphere, nitrogen; sliding velocity, 4600 feet per minute; load, 1000 grams; run duration, 1 hour; ambient temperature, 1000° F.

disk temperatures of 75°, 500°, and 1000° F. The lubricant used in these experiments was a polyphenyl ether (five-ring isomeric). The lubricant was supplied to the specimens at a rate of 0.55 cubic centimeter per minute in a nitrogen-gas mist. The lubricant was examined under three different conditions. The conditions were (1) as received, (2) degassed, and (3) degassed with dibromotetrafluoroethane added. The results obtained in the experiments with the polyphenyl ether are presented in figure 2. With the as-received oil, the friction and wear for René 41 was relatively low at 75° F. At 500° F both friction and wear increased. At 1000° F an increase in rider wear for René 41 was observed; however, the friction coefficient decreased. Very little carbonaceous residue was found on the disk-specimen surfaces in the experiments at 500° and 1000° F. Metal wear debris appeared as fine, shiny, metallic platelets, as shown in the photomicrograph of figure 2.

The second set of experiments was conducted with the degassed polyphenyl ether. At all three temperatures, 75°, 500°, and 1000° F, an increase in both friction and wear was observed with the degassed oils. At 500° F, for example, an increase in wear of an order of magnitude (relative to the as-received oil) occurred with degassing of the oil. These results indicate the significance of entrained gases on the lubricating behavior of polyphenyl ether.

The results of the third set of experiments with 10 percent by volume dibromotetrafluoroethane added to the degassed polyphenyl ether are also presented in figure 2. The objective of adding the bromine compound was twofold, to reduce friction and wear and to provide a snuffer agent for the lubricant. The additive decreased the viscosity of the polyphenyl ether considerably. The addition of the bromine-containing compound did not reduce friction and wear of the rider specimen, and wear was higher at 75° and 500° F than that obtained even with the degassed oil. At 1000° F, however, a slight decrease in wear of the René 41 rider was observed. Since dibromotetrafluoroethane is a very stable organic molecule, it was not expected to decompose until such time as relatively high surface temperatures were reached. The difference in surface profile between the René 41 disk specimens run with degassed polyphenyl ether and the polyphenyl ether containing 10 percent by volume dibromotetrafluoroethane is shown in figure 3.




(c) Degassed polyphenyl ether with 10 percent dibromotetrafluoroethane added.

Figure 4. - Coefficient of friction for René 41 sliding on René 41. Lubricant, polyphenyl ether; flow rate, 0.55 cubic centimeter per minute; atmosphere, nitrogen; sliding velocity, 4600 feet per minute; load, 1000 grams; ambient temperature, 75° F.

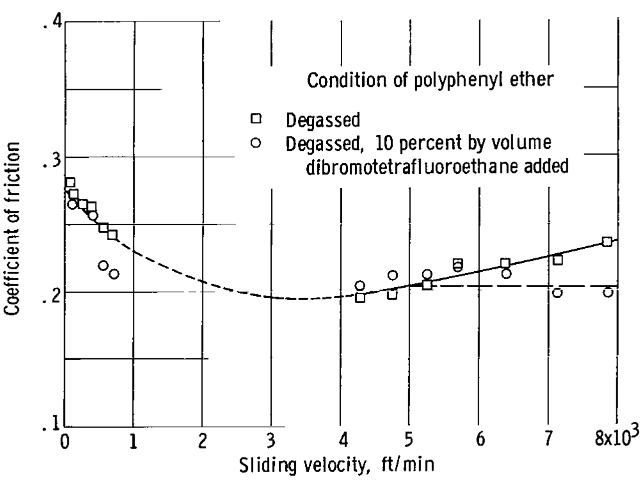



Figure 5. - Coefficient of friction for René 41 sliding on René 41 at various sliding velocities. Lubricant, polyphenyl ether; flow rate, 0.55 cubic centimeter per minute; atmosphere, nitrogen; load, 1000 grams; ambient temperature, 500° F.

Although the difference obtained with polyphenyl ethers at 75° F under the three sets of lubricating conditions were not marked, the friction traces obtained in the three experiments are quite different. Examination of figure 4 indicates that the straight polyphenyl ether (not degassed) caused very little change in the trace. With the degassed oil, however, numerous metal contacts through the oil film apparently occurred. The addition of the bromine-containing fluid to the degassed polyphenyl ether resulted in an initial friction trace that very closely approximated that obtained with the degassed oil alone. After about 47 minutes of the experiment, the friction trace more closely resembled that obtained with the oil containing entrained gases. These results indicate that the entrained gases afforded the specimens surface protection and that with the halogen-containing gas time is required for the formation of a protective surface film.

Since changing sliding velocities can result in a change in frictional energy and surface temperature, some friction experiments were conducted at 500° F with René 41 sliding on René 41 at various sliding velocities with the degassed polyphenyl ether and the degassed polyphenyl ether containing dibromotetrafluoroethane as the lubricants. The results obtained are presented in figure 5. Relatively little difference is shown.

Results obtained in friction and wear experiments with the paraffinic resin under the same conditions as reported for the polyphenyl ether are presented in figure 6. The data at 75°, 500°, and 1000° F show very little difference in friction and wear as a result of degassing the oil. The addition of dibromotetrafluoroethane caused some reduction in both friction and wear for René 41 at 500° and 1000° F over the results obtained with the as-received and degassed oils. The greatest difference occurred at 1000° F.

In order to examine further the ability of the dibromotetrafluoroethane to form protective surface films, friction experiments at variable loads were conducted at 500° F with René 41 and the degassed paraffinic-resin blend and the degassed resin blend containing 10 percent by volume dibromotetrafluoroethane as the lubricants. The results obtained are presented in figure 7. The degassed paraffinic resin lowered the friction coefficient more initially (light loads) than did the degassed paraffinic resin containing 10 percent by volume dibromotetrafluoroethane. As the load was increased, however, to about 950 to 1100 grams, a surface film was apparently formed from the reaction of dibromotetrafluoroethane with the René 41 surface, and at loads of 1000 grams and above, the friction force decreased with the paraffinic resin containing 10 percent by volume dibromotetrafluoroethane. Generally, no benefit was gained from the addition of the bromine-containing gas to the degassed paraffinic resin.

Since the silicone fluids have desirable thermal stability and have been successfully used at high temperatures, some friction and wear experiments were conducted with a chlorinated

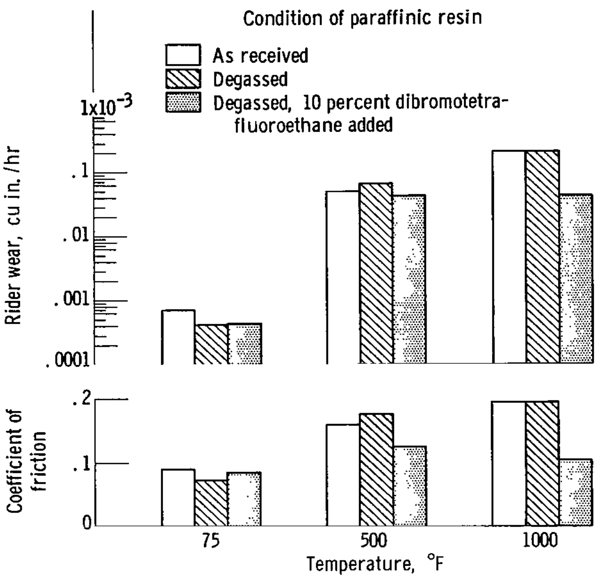



Figure 6. - Coefficient of friction and rider wear of René 41 sliding on René 41. Lubricant, paraffinic resin; flow rate, 0.55 cubic centimeter per minute; atmosphere, nitrogen; sliding velocity, 4600 feet per minute; load, 1000 grams; run duration, 1 hour.

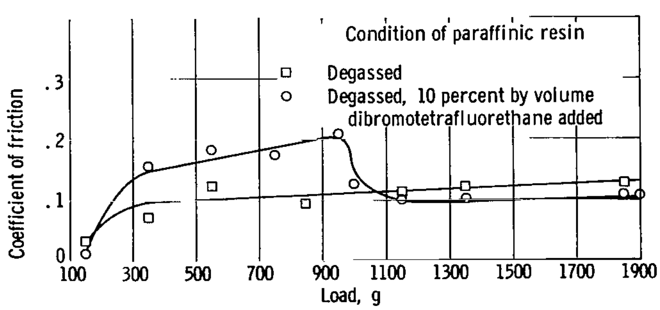



Figure 7. - Friction coefficient as function of load for René 41 sliding on René 41. Lubricant, paraffinic resin; flow rate, 0.55 cubic centimeter per minute; atmosphere, nitrogen; sliding velocity, 4600 feet per minute; temperature, 500° F.

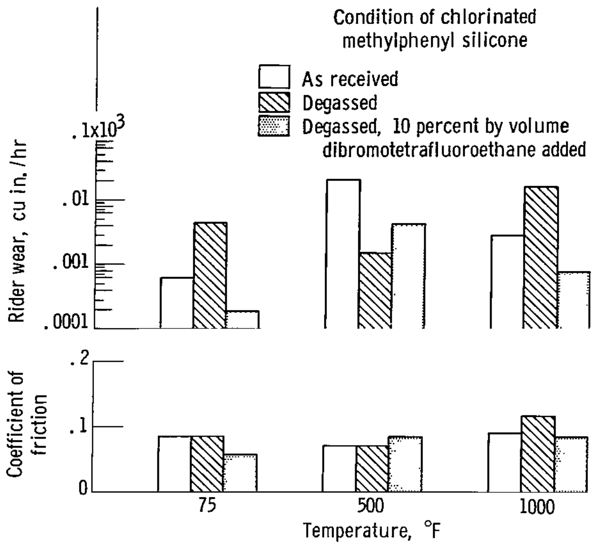
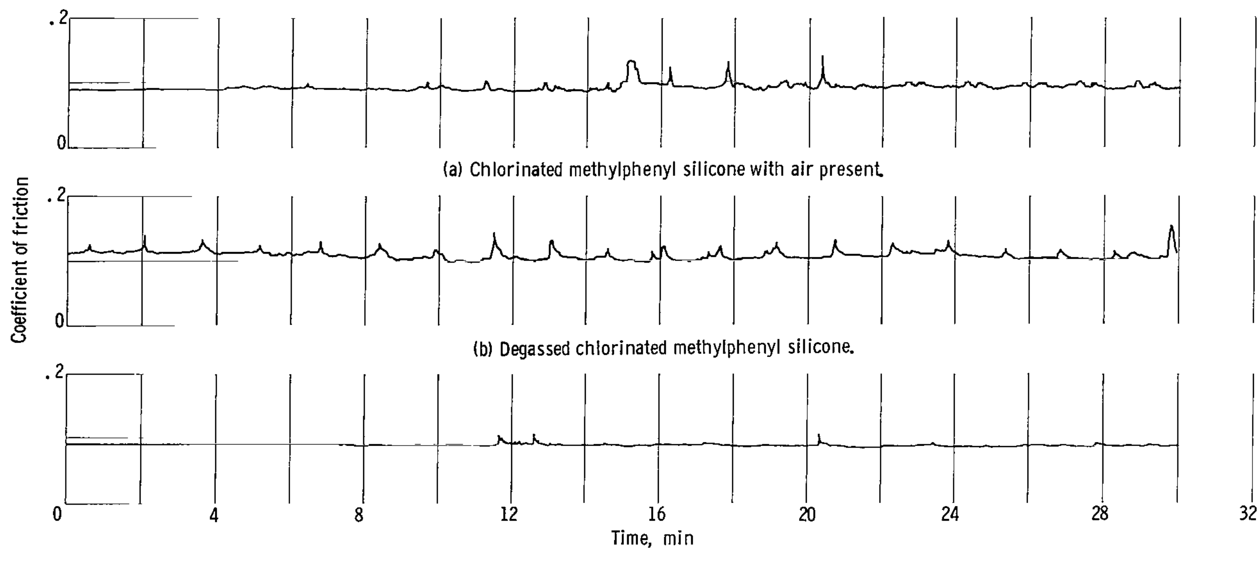



Figure 8. - Coefficient of friction and rider wear for René 41 sliding on René 41 at various temperatures. Lubricant, chlorinated methylphenyl silicone; flow rate, 0.55 cubic centimeter per minute; atmosphere, nitrogen; sliding velocity, 4600 feet per minute; load, 1000 grams; run duration, 1 hour.

methylphenyl silicone under the same conditions as used in examining the polyphenyl ether and the paraffinic resin. The results obtained in the experiments with a chlorinated methylphenyl silicone are presented in figure 8. In general, better friction and wear characteristics were observed with the as-received lubricant at all three temperatures, $75^{\circ}$, $500^{\circ}$, and $1000^{\circ}$ F, than were obtained with the polyphenyl ether and the paraffinic-resin blend under the same conditions. With the degassed oil an increase in rider wear resulted at $75^{\circ}$ and $1000^{\circ}$ F; a decrease in wear was observed at $500^{\circ}$ F. These results were verified a number of times. With the addition of dibromotetrafluoroethane to the chlorinated methylphenyl silicone, the rider wear decreased at $1000^{\circ}$ F by a factor of nearly 30.

Although no marked differences in friction coefficient were observed with the chlorinated methylphenyl silicone when the




(c) Degassed chlorinated methylphenyl silicone with 10 percent by volume dibromotetrafluoroethane added.

Figure 9. - Coefficient of friction for René 41 sliding on René 41. Lubricant, chlorinated methylphenyl silicone; flow rate, 0.55 cubic centimeter per minute; atmosphere, nitrogen; sliding velocity, 4600 feet per minute; load, 1000 grams; ambient temperature, 1000° F.

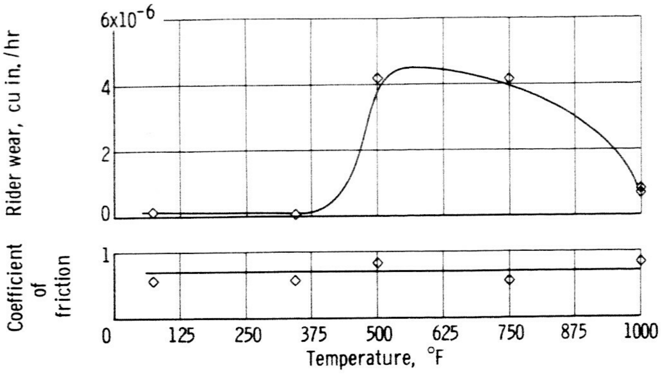



Figure 10. - Coefficient of friction and rider wear for René 41 sliding on René 41 at various temperatures. Lubricant, chlorinated methylphenyl silicone with 10 percent by volume dibromotetrafluoroethane; flow rate, 0.55 cubic centimeter per minute; atmosphere, nitrogen; sliding velocity, 4600 feet per minute; load, 1000 grams; run duration, 1 hour.


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Figure 11. - Surface deposits on René 41 disk specimen. Lubricant, chlorinated methylphenyl silcone; flow rate, 0.55 cubic centimeter per minute; atmosphere, nitrogen; sliding velocity, 4600 feet per minute; load, 1000 grams; run duration, 1 hour; ambient temperature, 1000° F.

various treatments were used, a difference in the friction trace was obtained, as indicated in figure 9. With the lubricant containing entrained water, oxygen, and nitrogen at 1000° F, the friction trace sporadically indicated numerous metal-metal contacts through the oil film, as evidenced by the increases in friction coefficient. When the lubricant was degassed, this contact seemed to occur with a high degree of periodicity. When dibromotetrafluoroethane was added to the chlorinated methylphenyl silicone, this periodic friction increase was not observed.

Results of friction and wear of René 41 sliding on René 41 lubricated with 10 percent by volume dibromotetrafluoroethane in degassed chlorinated methylphenyl silicone at temperatures to 1000° F are presented in figure 10 (note that the rider-wear scale is linear). The friction coefficient was very nearly the same over the entire temperature range. Above 375° F, however, the rider wear increased markedly and remained high even beyond 750° F. At 1000° F, the rider wear decreased. This decrease may be associated with the formation of metallic bromides. Numerous surface deposits were observed at 1000° F with the chlorinated methylphenyl silicone that contained entrained gases, as indicated by figure 11. Fewer deposits were observed with the degassed oil and the degassed oil containing dibromotetrafluorethane.

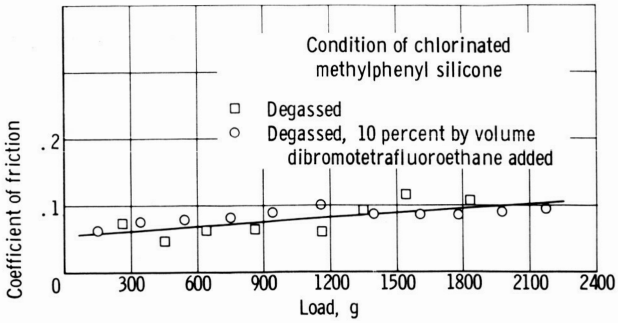
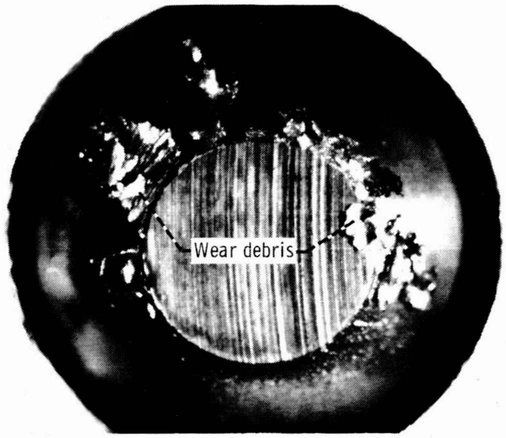



Figure 12. - Friction coefficient as function of load for René 41 sliding on René 41. Lubricant, chlorinated methylphenyl silicone; flow rate, 0.55 cubic centimeter per minute; atmosphere, nitrogen; sliding velocity, 4600 feet per minute; ambient temperature, 1000° F.




Rider specimen after use of degassed polypropylene.

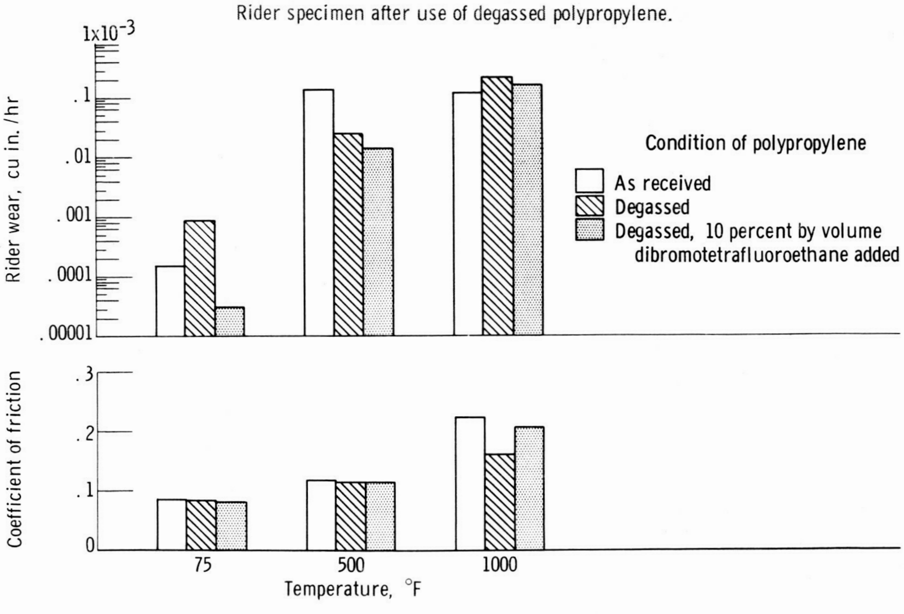



Figure 13. - Coefficient of friction and rider wear for René 41 sliding on René 41 at various temperatures. Lubricant, polypropylene; flow rate, 0.55 cubic centimeter per minute; atmosphere, nitrogen; sliding velocity, 4600 feet per minute; load, 1000 grams; run duration, 1 hour.

In order to determine the ability of the dibromotetrafluoroethane to form surface films, some experiments to determine friction coefficient as a function of load were conducted like those with the paraffinic resin. The experiments were conducted at 1000° F with the degassed chlorinated methylphenyl silicone bath with and without 10 percent by volume dibromotetrafluoroethane. The results obtained in these experiments are presented in figure 12. The results indicate no marked difference in the friction data for the two lubricating fluids.

The results of friction and wear experiments with a polypropylene fluid under the same conditions as the polyphenyl ether were examined and are presented in figure 13. A greater decrease in wear was observed with the degassed oil than with the as-received oil. Examination of rider wear indicated that with entrained gases present the debris was a fine black powder; while with the degassed oil, the wear debris remained attached to the rider as metal ribbons (shown in the photomicrograph of fig. 13). With the gases present in the oil, it is believed that the fine black debris was metal that had been oxidized. With the degassed oil, however, oxygen availability was reduced, and insufficient film was formed on the particles to prevent them from adhering to each other.

The bromine-containing compound dibromotetrafluoroethane afforded surface protection for René 41 when added to some of the lubricating fluids examined. With others, such as the polypropylene, this effect was not discernible. This particular compound has been shown to be an effective reactive-gas lubricant (refs. 10 and 11) when used with metal surfaces; however, the temperatures at the interface in this investigation with oil lubricants may not be sufficiently high to promote thermal decomposition of the molecule. This particular additive molecule has a high degree of thermal stability. A greater degree of effective surface protection might be achieved with a somewhat less thermally stable molecule. For example, this particular molecule is basically symmetrical; that is, there is one bromine atom on each of the two carbon atoms. A molecule containing both bromine atoms on a single carbon atom would be somewhat less stable and might therefore prove more effective as an oil additive.

In order to determine the ability of dibromotetrafluoroethane to suppress the ignition of the oils used in this investigation, some spontaneous-ignition-temperature experiments were conducted with these oils with and without 10 percent dibromotetrafluoroethane. The method

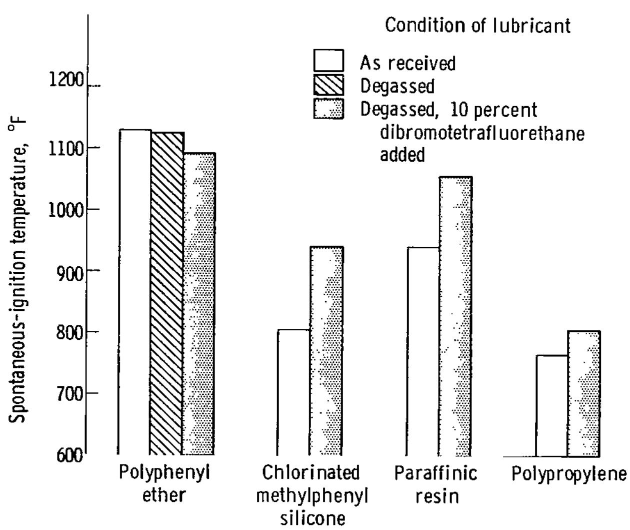



Figure 14. - Spontaneous-ignition temperatures of various lubricants with and without dibromotetrafluoroethane.

used for these determinations was the same as that employed in reference 9. The results obtained are presented in figure 14. The ignition temperature obtained for the polyphenyl ether agrees with that indicated by the oil supplier. In order to determine the influence of entrained gases on the ignition of the polyphenyl ether, experiments were conducted with degassed oil samples. Degassing appears to have very little influence on the ignition temperature of the oil. The addition of 10 percent dibromotetrafluoroethane to the polyphenyl ether resulted in a slight decrease in the ignition temperature of the fluid. This experiment was repeated numerous times with the same result. With the other three oils of figure 14 an increase in spontaneous-ignition temperature was observed. The greatest increase resulted with the silicone fluid; an increase of $135^{\circ}$ F was observed in the spontaneous-ignition temperature.

## SUMMARY OF RESULTS

Based on the friction, wear, and spontaneous-ignition-temperature data obtained in an investigation of various potential lubricating and hydraulic fluids as boundary lubricants for René 41, the following remarks can be made:

1. In general, the addition of 10 percent dibromotetrafluoroethane did not improve the lubricating characteristics of the polyphenyl ether and the polypropylene fluids, but it did improve the performance of the paraffinic resin and more markedly the performance of the chlorinated methylphenyl silicone at $1000^{\circ}$ F.

2. Of the four oils examined in the friction and wear studies, the most marked effects of degassing were obtained with the polyphenyl ether. At $500^{\circ}$ F, in the most extreme case, the wear of René 41 increased by an order of magnitude after the oil had been degassed.

3. The addition of 10 percent dibromotetrafluoroethane increased the spontaneous-ignition temperature for the paraffinic resin, the methylphenyl silicone, and the polypropylene. With the polyphenyl ether, however, no marked change in spontaneous-ignition temperature was observed with the addition of dibromotetrafluoroethane.

4. In friction and wear experiments with nondegassed oils under boundary lubricating conditions, the nickel-base alloy René 41 was, in general, most effectively lubricated by the chlorinated methylphenyl silicone fluid at $1000^{\circ}$ F.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, November 23, 1964.

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